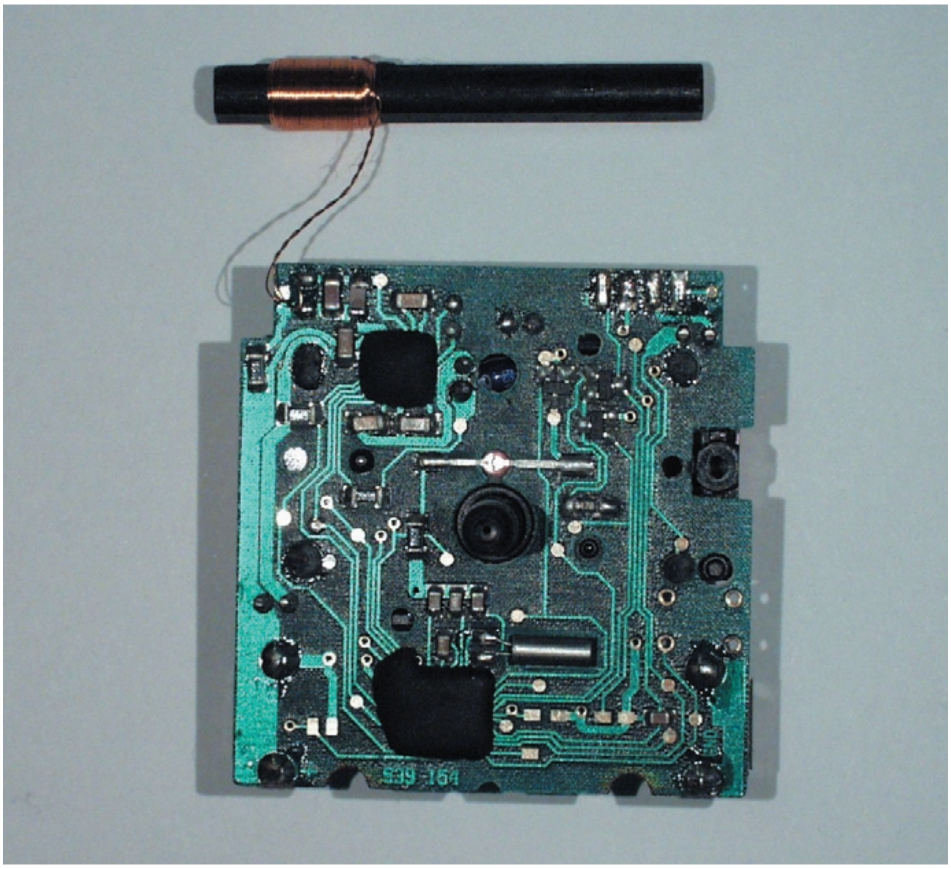
Radio Controlled Clocks

a peek under the bonnet

Recent advancements in circuit integration have drastically reduced the production costs of radio-controlled clocks. These days they are not much more expensive than their conventional quartz counterparts. This article gives us an insight into the design of an analogue radio controlled clock.



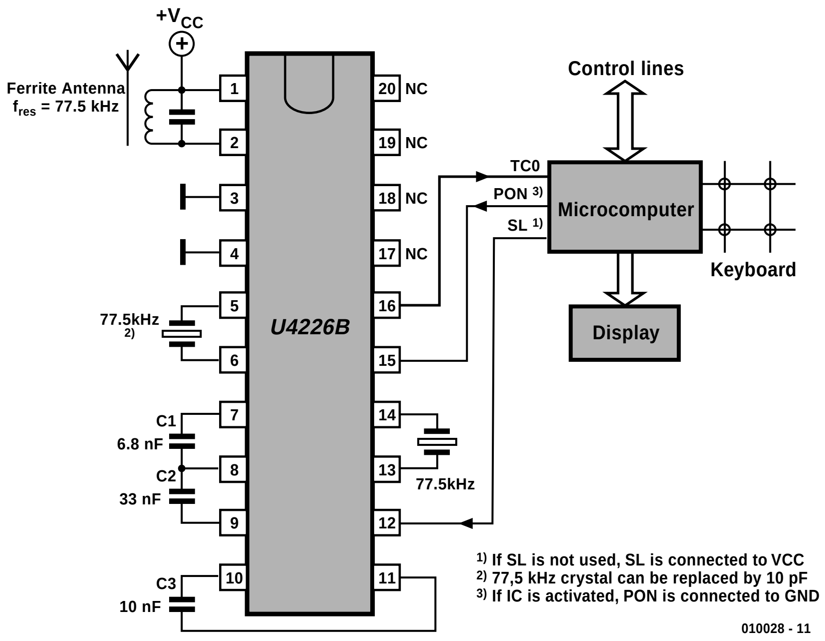
Convenience and reliability are probably the biggest attractions of a radio controlled clock. Standard quartz clocks are accurate enough for most purposes but with a radio controlled clock there is no longer the need to periodically synchronise it, compensate its movement or add or subtract an hour. All it needs is a fresh battery every so often and it will carry on showing the precise time and date through leap years, leap seconds, BST and GMT.

A look inside a modern radio controlled clock with a liquid crystal display (LCD) will typically reveal just two ICs and a few passive components. The first IC is connected to an antenna and receives the time signals while the second IC is responsible for decoding this time signal and displaying it. The quality of the radio is largely dependent on the microcontroller software. It governs the ease of use of the clock, the reliability of the displayed time and the battery life. With clever programming it is also possible to recover coded time signals despite radio interference.

TIME SIGNAL RECEPTION

Radio stations transmitting time signals invariably use amplitude modulation in the long wave (LW) band. This operating frequency ensures optimum coverage thanks to ground wave propagation in the VLF band. The two basic techniques used for detecting this type of signal are superhetrodyne or direct conversion. At these low frequencies a direct conversion receiver is generally preferred because it requires very few external components to tune the receiver (typically two to four capacitors and a crystal). It also intrinsically consumes less power than a superhet. Further developments will undoubtedly lead to improved specifications for such receiver chips giving an even lower operating voltage and current along with improved interference rejection.

The same receiver configuration can be used to receive all the major time signal transmitters. Currently in the UK we have MSF Rugby, in the US they have the WWVF transmitter at Fort Collins (both operate on



1) If SL is not used, SL is connected to VCC
2) 77,5 kHz crystal can be replaced by 10 pF
3) If IC is activated, PON is connected to GND

Figure 1. Application diagram of the U4226B from Temic (Atmel).

60 kHz). In Germany the DCF 77 transmitter at Mainflingen operates on 77.5 kHz and the Japanese transmitter near Tokyo operates on 40 kHz. Almost all radio clocks use one of two receiver chips, either the Temic U4226B shown in **Figure 1** or the UE6002 shown in **Figure 2.** This chip is produced by HKW Elektronik and is distributed in the UK by Galleon Systems Ltd. Both these chips use the direct conversion principle where a high-gain amplifier and filter are tuned to the frequency of the receive signal. One or two external crystals are needed to fix the receiver selectivity. The output consists of a digital data stream containing the time code information from the transmitter.

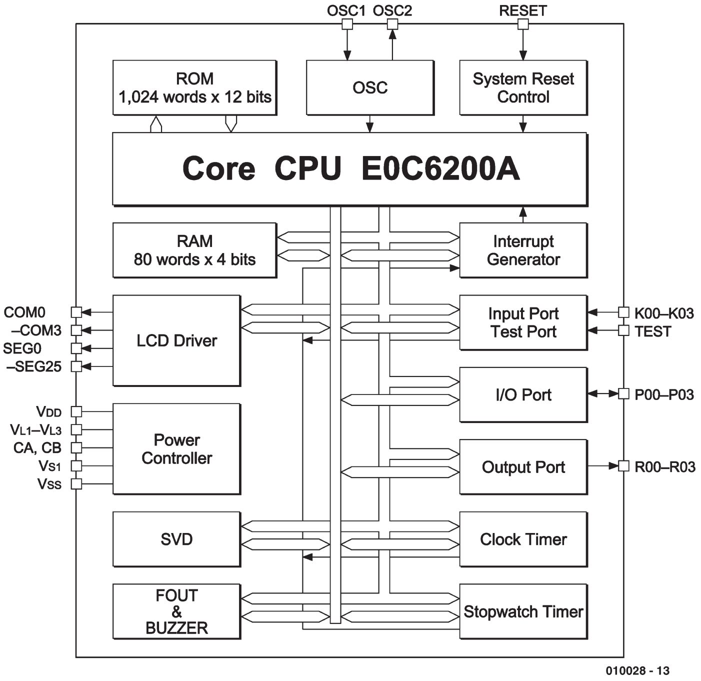


Figure 2. Block diagram of the UE6002 from HKW-Elektronik.

The Microcontroller

The majority of radio controlled clocks are battery powered. When choosing a microcontroller for this application it is important for the circuit designer to select one that can operate at a low voltage (preferably with just one cell) and will use as little power as possible to prolong battery life. Seiko Epson produce a 4-bit microcontroller family designed specifically for this application (**Figure 3**). The E0C6S37 is one variant of this family and has the following main characteristics:

- 1K ROM.
- 80 Nibble RAM.
- 4 inputs / 4 outputs.
- 26 Segment/4 Common LCD driver.
- 1 Timer, 1 stop watch timer.
- 2 kHz alarm tone output.
- 1.2V Threshold for voltage supervision circuit.
- Supply voltage 0.9-2.0 V.
- Current consumption typically 2.5 µA at 32.768 kHz.

This controller is intended for large scale production applications and is not intended for hobbyists. The development tools are relatively expensive and there are no OTP variants of the chips available for hobby applications. The programmed controllers are supplied in large quantities so it only becomes economically viable to use this controller for mass-produced products. Once the software for the application has been developed and thoroughly tested by the customer it is sent to the IC manufacturer where the chip mask is programmed. This process can take up to four weeks and is relatively costly. Any mistakes in the software design at this stage cannot be corrected and involve a repeat of the mask making procedure with additional expenditure in both time and money. To reduce production costs, the finished mask programmed controller chip is glued directly to the target PCB where a bonding machine makes connections between the input/output pads of the chip and the PCB. At this stage the chip is still completely naked and requires a blob of opaque epoxy based glue to cover its embarrassment. This coating gives protection from the environment and provides physical support for the chip and its fine bonding wires. A final bake will fully cure this epoxy layer.

The essential tasks that the microcontroller needs to take care of include:

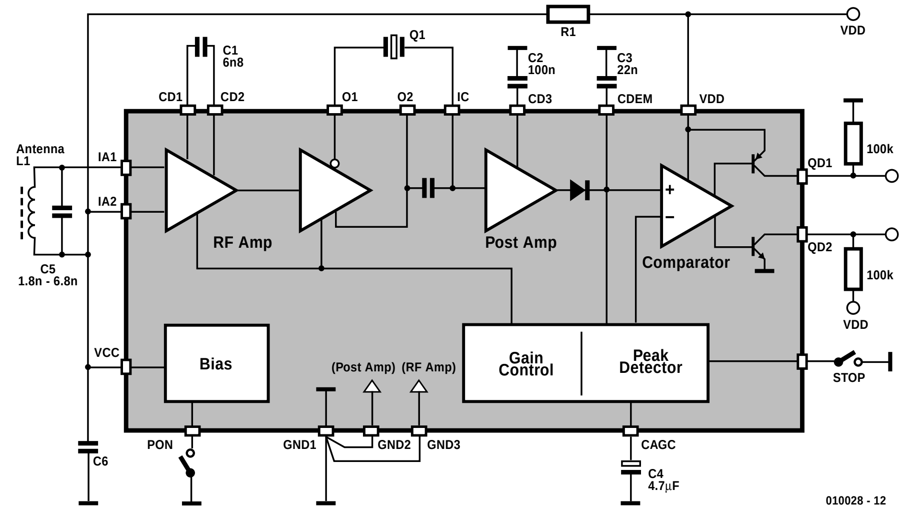


Figure 3. Internal block diagram of the E0C6S37 microcontroller from Seiko Epson.

- Display control.
- Push button scanning.
- Monitoring the battery voltage.
- Checking alarm time.
- Decoding the radio signal.
- Controlling the clock hands.
- Checking the reference position of the clock hands.
- Controlling the alarm sound.
- Running test routines during manufacture and testing.

A TYPICAL RADIO CONTROLLED CLOCK

Figure 4 shows the circuit diagram for a typical radio controlled clock using an analogue display, i.e., an hour and minute hand rather than an LCD. When the battery is inserted into the clock, the microcontroller will not know exactly where the hands are pointing, so it needs to calibrate the mechanical hand position. There is usually a reference point marked on internal gears attached to the hands. In our circuit, D1 and T3 form a light gate to detect a hole in the gears of the clock. This hole generates a signal when the hands are pointing at precisely 12 o'clock. This reference position is checked daily to ensure that no mechanical slippage has occurred.

IC3 is an E5130 stepper motor driver chip, it drives the two stepper motors in the clock attached to the second hand and the minute hand. This IC is again designed for such low voltage and current applications. The transducer Bz1 is driven by transistors T1 and T2 to provide a 2 kHz alarm tone. When the alarm time is reached, transistor T2 is first switched on to begin the alarm tone. If you are still in slumber mode and have not hit the alarm off button within 10 seconds, transistor T1 will switch on to form a bridge across resistor R1 that allows more current to flow through Bz1, thereby increasing the alarm volume (crescendo function). Transistors T1 and T2 are driven directly from the controller chip outputs and internal short circuit protection on the outputs of this chip ensure that excessive transistor base current is prevented. All control buttons on the clock are connected to the input port of the controller chip and these are fitted with internal pull-up resistors.

The stepper motor output control signals SEG0 to SEG3 can be mask programmed to drive an LCD display and there are also an additional 26 outputs available for use.

The interface between the controller and the time code receiver chip consists of three connections.

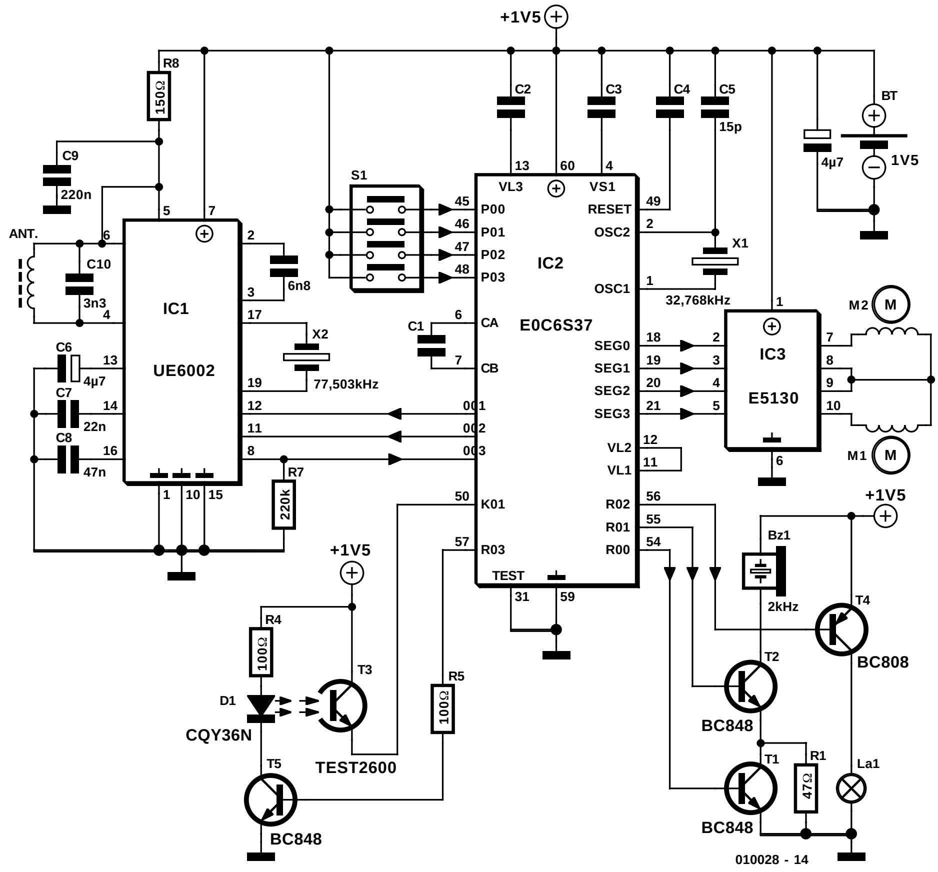


Figure 4. Circuit diagram of a DCF radio clock.

The received time code signal is sent to the microcontroller from pin 8 of the receiver chip. Pin 11 of the receiver chip is a ‘power down‘ pin and allows the microcontroller to switch off the receiver chip to conserve power. The third line on pin 12 is used to mask out any interference generated locally by the microcontroller outputs. Analogue clocks employ stepper motors to move the minute and second hands and each step pulse generates a relatively high pulse of RFI lasting approximately 500 ms (60 ms stepper pulse plus resonance decay time). It is important that these stepper pulses are not output during critical times in each second of the received time signal so the movement of the hands must be exactly synchronised with the time signal. A signal on this line will tell the receiver chip that a stepper pulse is being sent and it will effectively hold the time signal output at its current level until the interference has passed, thereby masking out the interference from its output signal.

A coil wound on a ferrite rod together with capacitor C10 form the antenna for this 77.5 kHz system.

During use, once a battery is connected to the circuit, the microcontroller will move the clock hands until it finds the reference position. The time code receiver will then be switched on and the controller waits until it has received two complete valid messages. This may take more than two minutes. If any part of the message becomes corrupted by local interference such as a thunderstorm or multi-path signal distortion (reflections), the controller will wait until it receives two valid messages before it turns off the time code receiver, calculates the hand position, and moves the hands. The time code receiver is periodically turned on by the microcontroller during normal operation and the displayed time is compared to the received time code. When these two times do not correspond (e.g., when the changeover between GMT and BST occurs) the controller will wait for confirmation by receiving further time code messages before it updates the displayed time.

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Web Links

www.vishay.com/products/optoelectronics/
www.atmel-wm.com
www.epson-electronics.de/download/down4bit.htm#E0C6S37
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